A comparative analysis of the Late Variscan uranium mineralization of the Shkara massif (Greater Caucasus, Georgia) and of the late variscan uranium deposits of the central and western Europe

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Abstract. At the head of Enguri river, along the Main Thrust of the Greater Caucasus, in the Shkara crystalline massif, the high concentration uranium mineralization was discovered. The parent rocks of the mineralization are represented by biotite plagiogranites and migmatites. LA-ICP-MS $^{206}Pb/^{238}U$ dating of zircons from the plagiogranite vein indicates an age of 310.2±7.5. The Shkara mineralization is represented by hydrothermally generated uraninite veins and nests. According to ICP-MS-ES analyses, in this rocks, the Th content varies from ~25 ppm to ~90 ppm, and the U varies between ~20 ppm to ~370 ppm. Geochemical studies of the uraninite veins on the JXA-8230 electron probe microanalyzer have shown that the U mineral is high-temperature Th-bearing uraninite that consists of uranium, thorium, lead and yttrium. The overall chemical U-Pb ages of the uraninite veins, to corresponds 291±14 Ma.

According to the composition, geodynamic setting, tectonic localization, isotopic age and type of mineralization, the studied U mineralization is in full correlation with the same type of the Late Variscan Uranium Deposits of the Central and Western Europe. Therefore, we believe that investigation of the Shkara U mineralization is important both from a scientific and an economic point of view.

1. Introduction

The dominant part of the uranium deposits in granites is associated with the Late Carboniferous hydrothermal veins of the Variscan orogeny. These veins are localized in brecciated or fault zones that may occur in both the center and peripheries of granitic massifs (e.g., Rene 2012). In Europe, those types of uranium deposits have been identified in the Iberian Massif, Spain (e.g., López-Moro et al. 2019); in the Armorican (Ballourd et al. 2017) and Central Massifs (Cuney 2014) France; in the Schwarzwald Massif, Germany (Hofmann and Eikenberg 1991); and in the Bohemian Massif, the Czech Republic (e.g., Rene, Dolníček 2017).

In this study, we performed a comparative analysis recently discovered Shkara uranium mineralitation of the Greater Caucasus with the well-studied Late Variscan uranium deposits of Central and Western Europe. We determined the characteristics of uranium occurrences of the Sakhara massif, for the purpose of optimally planning its further economic investigation.

2. Brief Geology of the Greater Caucasus

The Greater Caucasus fold-and-thrust belt is the northernmost expression of the Caucasus orogen and is linked to the southern margin of the Precambrian Scythian Platform. In the structure of the Greater Caucasus, two major formations are distinguished: pre-Jurassic crystalline basement and Meso-Cenozoic sedimentary and magmatic formations. It is assumes that the pre-Jurassic basement was an active continental margin in the Paleozoic, along which Paleo-Tethys oceanic crust was subducted to the north (e.g., Gamkrelidze 1986; Okrostsvaridze and Tormey 2011).

The basement complex of the Greater Caucasus has a collage construction, which is thrust over on the Lower Jurassic formations along the Main Thrust of the Greater Caucasus. Within the basement complex, four regional structural-tectonic zones are recognized from south to north: Southern Slope, Main Range, Fore Range and Bechasyn (e.g., Gamkrelidze et al. 2020)

Variscan plutons are localized in both the Pass and Elbrus subzones of the Main Range Zone. In the Pass Subzone, the plutons are mainly represented by I-type quartz-diorites and granodiorites, while the Elbrus Subzone - by S-type two-mica granites. In both subzones, these plutons cut through the Lower-Middle Paleozoic gneiss-migmatite complex. It is noteworthy that, in the infrastructure, as well as in the intersected plutons, 0.3–4.5 m thick plagiogranite veins are developed.

The Greater Caucasus is rich in U, As, Sb and other metals however, uranium mineralization was not known here. In 2021, hydrothermal uranium mineralization was discovered here in the headwaters of the Enguri River, in the Shakha crystalline massif (Okrostsvaridze et al. 2022a).

3. The Shakha crystalline massif

It is located at the headwaters of the Enguri river, and thrust over in the Lower-Middle Jurassic black clay shales. The massif builds a ~15 km long and ~5 km high ridge and is composed of Lower to Middle Paleozoic biotite schists, gneisses and migmatites. It is cut by a huge granitoid pluton of the Late Variscan generation.

The Shkhara pluton is interpreted as a mantle-crustal formation, which formed under an island arc geodynamic setting. It is predominantly composed of granodiorites, with a lesser amount of granites and quartz-diorites (Okrostsvaridze, Tormey 2011). Zircons in granodiorites of the main phase of the Shkhara pluton and enclosing biotite-gneisses were dated by the zircon LA-ICP-MS U-Pb method. This study found a weighted mean 206Pb/238U age of 316.9±8.8 Ma for the Shkhara pluton granodiorites and of 488.5±8.5 Ma for of the biotite gneiss enclave (Okrostsvaridze et al. 2022b).

Biotite plagiogranite veins of hydrothermal generation of different thicknesses(0.5–4 m) often cut the Shkhara Massif. They occur along the Main Thrust of the Greater Caucasus and mark the Paleozoic suture zone. Zircons of one sample (21Geo-11) from the U-Th bearing plagiogranite vein was dated using the U-Pb method. The weighted mean $^{206}Pb/^{238}U$ age of these zircons corresponds to 310.2±7 Ma (Okrostsvridze et al. 2022b).

4. U mineralization of the Shakha massif

During an expedition in 2021, the elevated radiation dose (μSv/h>1) was detected in several biotite plagiogranite veins. We studied the back-ground radiation in the field using the FAG-FH40F2 dose rate meter (Fig.1).

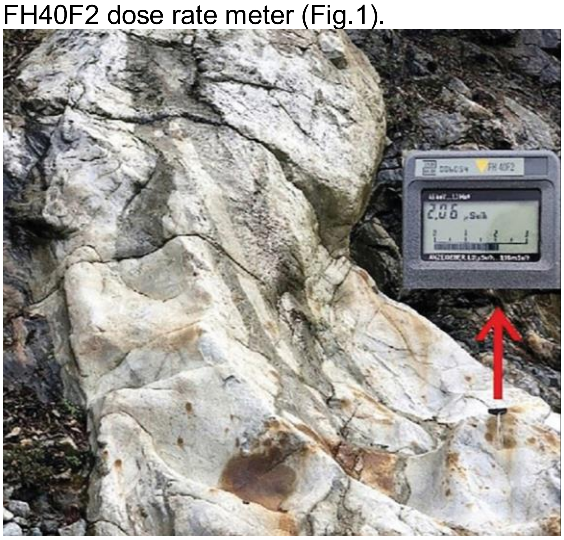

Figure 1. One of the Shkhara plagiogranite vein with FAG-FH40F2 dosimeter showing the dose 2.06 μSv/h.

Uranium and thorium mineralization of these rocks is associated with uraninite veins and nests, which are formed in biotite plagiogranites and migmatites (Fig. 2). This rock was identified as a hydrothermally altered biotite-quartz-plagioclase formation, in which the SiO_2 content varies in the range of 75-85%.

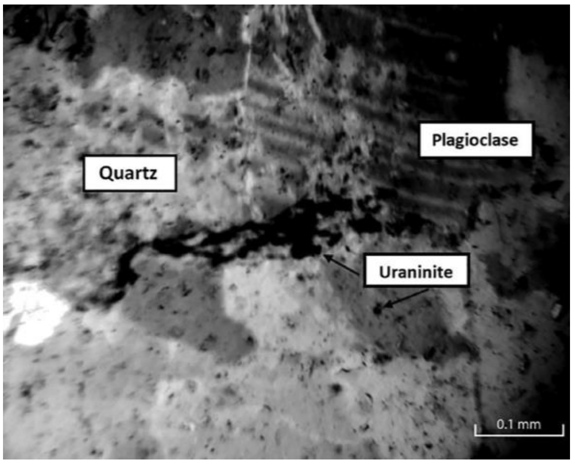

Figure 2. Typical mineralogy of the plagiogranite of the Shkhara Massif with vein and nests of uraninite (sample 21Sv8) (plane polarized light).

The whole-rock chemical compositions of these rocks were measured using ICP-ES analyses for 48 elements conducted by MS-Analytical laboratory (MSALABS), Canada. This chemical analysis has shown that the content of Th in this rock varies from 25 to 90 ppm and the content of U changes from 55 to 368 ppm.

We studied the geochemistry and chemical U-Pb age of Shkhara uraninite veins, using a JEOLJXA853F, at the GFZ in Potsdam (Fig.3).

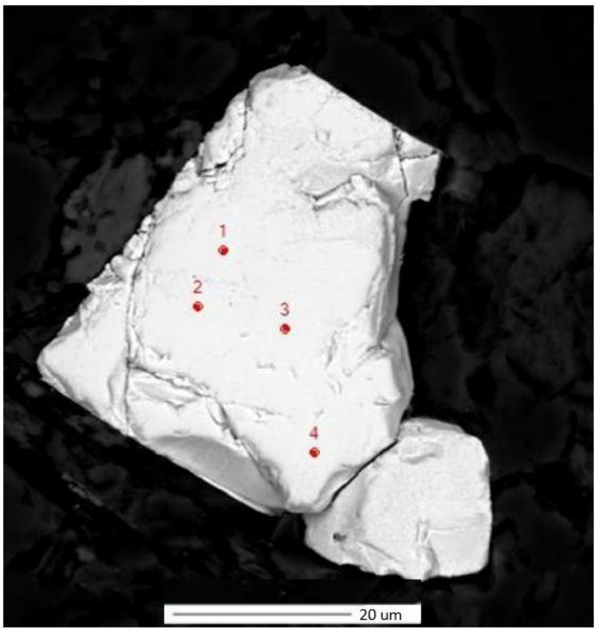

Figure 3. Dots of chemical analysis of uraninite graine. (Sample 21Ge1) of the Shkara U mineralization.

Geochemical studies have shown that the uranium mineral is high-temperature Th-bearing uraninite that consists of uranium, thorium, lead and yttrium. For example, In the 21G1 sample the UO_2 composition varies from 79.5% to 82.6 %, ThO_2 – from 6.7% to 8.4 %, PbO – from 2.95 to 3.9%, Y_2O_3 – from 1.15 to 3.77%.

According to Frimmel et al (2014), all examples of low-temperature hydrothermal uraninite do not contain Th (U/Th > 1000), while those formed at higher temperatures (>450 °C) usually have a higher ThO_2 content (U/Th < 100). If we take into account the results of this study, the studied uraninite should be considered a high-temperature formation, because in them the U/Th ratio varies between 9.5 and 11.5.

As for the chemical U-Pb age of the uraninite veins of the Shkara massif. The overall age of 4 samples corresponds to 291±14 Ma, which are the latest Carboniferous-early Permian period.

Late Variscan Uranium Deposits of the Central and Western Europe

In Central Europe, uranium deposits are mainly associated with the Bohemian and Schwarzwald, massifs, and in Western Europe with the French Massif Central, Armorican and Iberian massifs.

The Bohemian Massif hosts many uranium deposits of various sizes and genetic types and is the largest uranium ore district in Europe. Two principal types of uranium deposits can be distinguished in the Bohemian massif. The first type is represented by low-grade uranium mineralisation disseminated in strongly hydrothermally altered and mylonitized rocks. The second type includes vein-type deposits, characterized by open-space crystallization of hydrothermal minerals, often giving rise to very high-grade ores. The most important examples of vein-type uranium mineralisation of the Bohemian Massif are Příbram and Jáchymov (Rene, Dolnicek 2017).

In Schwarzwald massif (southwest Germany) Krunkelbach uranium deposit is represented by felsic vein-type mineralization. Uraninite and pitchblendes are the main ore minerals. U-Pb and U-Xe-Kr results indicate a late Carboniferous formation age of 295±7 Ma for all veins of the deposit (Hofmann and Eikenberg 1991).

The French Massif Central is nowadays one of the major uranium-producing districts in the world. The majority of uranium deposits have got an uraninite-pitchblende hydrothermal vein-type. Uranium deposits are formed in extensional tectonics zones at about 300 Ma, while Uranium mineralization is related to the Early Permian hydrothermal processes (Marignac and Cuney 1999).

In the southern part of the Armorican Massif (NW France) the Guérande peraluminous leucogranite was emplaced in an extensional deformation zone at 310 Ma. Several vein-type U deposits and occurrences are spatially associated with this leucogranite. U-Pb dating on uranium oxides from the Pen Ar Ran and Métairie-Neuve deposits reveals three different mineralizing events. The first event at 296.6 ± 2.6 Ma (Pen Ar Ran) is sub-synchronous with hydrothermal circulations and the emplacement of late leucogranite dykes. The two last mineralizing events occur at 286.6 ± 1.0 Ma (Métairie-Neuve) and 274.6±0.9 Ma (Pen Ar Ran), respectively (Ballouard et al. 2017).

Uranium mineralization in Iberian Massif is related to strike-slip shear zones. Uranium ores are observed in extremely differentiated leucogranites, pegmatites and quartz veins with gneisses. U-Pb ages of albitites from the strike-slip shear zones is 304±6 Ma. Uranium-rich granites emplacement started 347.6±1.9 Ma ago and ended up by 320-315 Ma ago, while chemical ages of uraninite in granites are de.termined as 300.4±2.7 Ma and in episyenites – 304.3±5.7 Ma (Lopez-Moro et al. 2018).

Thus, as we can see from this brief overview, an important Uranium deposit of Central and Western Europe was formed during the Late Variscan orogeny (Late Carboniferous-Early Permian). However additional U mineralisation was produced during the Mesozoic because of the thermal reactivation linked with the Alpine orogeny (Marignac and Cuney 1999).

Discussion

Analysis of the Late Variscan Uranium Deposits of the Central and Western European showed that two principal types of uranium mineralization can be distinguished in them. First type is represented by low-grade uranium mineralisation genetically connected in hydrothermally altered and mylonitized rocks. The second type includes vein-type deposits, characterized by crystallization of hydrothermal minerals, often giving rise to very high-grade ores (Rene, Dolníček 2017.

The uraninite mineralization of the Shkara massif, investigated by us, is closer to the 2nd vein-type. It should be noted that during field work in 2022, high contents of thorium and uranium were traced in biotite gneisses and migmatites in the eastern part of the Shkara massif. The mineralization is present in the form of nests and unlike vein-type mineralization, it has a high thorium content (55-90 ppm) and a low uranium concentration (25-45 ppm). This mineralization remains to be studied, although it appears that both types (low-grade hydrothermally and high-grade vein-type) of mineralization may be present in the Skhara massif.

Both the Late Variscan uranium deposits of Central and Western Europe and the Shkhara uranium mineralization are spatially associated with regional fault structures. Almost identical to their host rocks (albitites, plagiogranites, biotite gneisses and migmatites). The age identity is also observed in the time of formation of the ore mineralization themselves (~275-295 Ma). Therefore, the time interval between the formation of the containing rocks and the ore mineralization is almost identical (~15 Ma). In conclusion, all discussed uranium deposits and mineralization are formed with post-orogenic extensional regime of the crust.

Unlike the Central and Western European Late Variscan uranium deposits, high thorium contents (~50-90 ppm) are recorded in the uranium ore mineralization of the Shkara massif. The high concentration of thorium in uraninite (U/Th<100) suggests that this mineral was formed under high temperature conditions (>450 °C) (Frimmel et al 2014). The high temperature of formation of uraninite and the high concentration of Th in it suggest that the hydrothemes that produced it were of Juvenile generation and not meteoritic. This would be a good explanation and a prerequisite that the uraninite mineralisation at Shkhara could become very large.

Conclusion

The conducted investigation showed that the uranium occurrences of the Shkhara massif is represented by the uraninite hydrothermal vein system. The content of Th in this rock varies from 25 to 90 ppm and the content of U changes from 20 to 370 ppm. The parent rocks of the mineralization are presented by biotite plagiogranites and migmatites. Zircon U-Pb age of these rocks corresponds to 310.2±7.5 Ma. Uranium mineral is presented by high-temperature Th-bearing uraninite that are formed in post-orogenic extensional regime of the orogeny. The overall chemical U-Pb ages of the uraninite veins corresponds to 291±14Ma, which is the latest Carboniferous-early Permian period.

According to the composition, geodynamic setting, tectonic localization, isotopic age and type of mineralization, the studied U occurrences are in full correlation with the same type of the Late Variscan Uranium Deposits of the Central and Western Europe. Therefore, we strongly believe that the exploration of the Shkara U mineralisation should continue in the future for scientific and/or economical purposes. For here, too, all geological preconditions are given to find uranium deposits of similar size as in the Bohemia, Black Forest, French Massif Central, Armorica and Iberia massifs.

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References

Ballouard, C, Poujol, M, Boulvais, P. et al (2017) Magmatic and hydrothermal behavior of uranium in syntectonic leucogranites: The uranium mineralization associated with the Hercynian Guérande granite (Armorican Massif, France). Ore Geology Reviews 80:309–331.

Cuney M (2014) Felsic magmatism and uranium deposits. Bulletin de la Société Géologique de France 185 (2), 75–92.

Frimmel HE, Schedel S, Brätz H (2014) Uraninite chemistry as a forensic tool for provenance analysis. Applied Geochemistry 48, 104–121.

Gamkrelidze, IP (1986) Geodynamic evolution of the Cau- casus and adjacent areas in Alpine time. Tectonophysics 127 (3–4), 261–277.

Gamkrelidze, I.P, Shengelia, D.M., Chchindaze, G., Lee, Y.-H., Okrostsvaridze A et al. (2020) U-Pb LA-ICP-MS dating of zoned zircons from the Greater Caucasus pre-Alpine crystalline basement: Evidence for Cadomian and Variscan evolution. Geologica Carpathica 71 (3):249–263.

Hofmann B, Eikenberg J (1991) The Krunkelbach uranium deposit, Schwarzwald, Germany; correlation of radiometric ages (U-Pb, U-Xe-Kr, K-Ar, 230Th-234U). Econ. Geol. 86:1031–1049.

López-Moro FJ, Romer L, Rhede D et al (2019) Early uranium mobilization in late Variscan strike-slip shear zones affecting leucogranites of central western Spain. Journal of Iberian Geology 45:223–243.

Okrostsvaridze A, Tormey D (2011) Evolution of the Variscan orogenic plutonic magmatism: The Greater Caucasus. Journal of Nepal Geological Society 43: 45–52.

Okrostsvaridze A, Lee YH, Tormey D, Skhirtlade I (2022a) U-Pb zircon chronological constraints for three stages of synorogenic plutonic magmatism of the Greater Caucasus Svaneti segment, Georgia. Journal Episodes 6:1-15.

Okrostsvaridze A. Bluashvili D, Gogoladze S, Gabrielashvili R (2022b) The discovery of U mineralization in the late Variscan plagiogranite vein of the Shkhara crystalline massif (Greater Caucasus, Georgia). Geologica Balcanica 51 (1): pp. 3–14.

Marignac C, Cuney M (1999) Ore deposits of the French Massif Central: insight into the metallogenesis of the Variscan collision belt. Mineralium Deposita 34:472-504.

René M (2012) Uranium hydrothermal deposits. In: Vasiliev, A.Y., Sidorov, M. (Eds), Uranium: Characteristics, Oc-currence and Human Exposure. Nova Science Publishers Incorporated, 211–244.

Rene M, Dolnicek Z (2017) Uraninite, Coffinite and Brannerite from Shear-Zone Hosted Uranium Deposits of the Bohemian Massif (Central European Variscan Belt). Minerals 7 (50):1-17.